Optimization of Electric Power Systems for Off-Grid Domestic Applications: An Argument for Wind/Photovoltaic Hybrids

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Research Advisor: ______________________________

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Abstract

The purpose of this research was to determine the optimal configuration of power sources relevant to different regions in the United States. The hypothesis was that regardless of region, the optimal system would be a hybrid incorporating wind technology, versus a photovoltaic hybrid system without the use of wind technology. The method used in this research was HOMER, the Hybrid Optimization Model for Electric Renewables. HOMER is a computer program that optimizes electrical configurations under user defined circumstances. According to HOMER, the optimal system for the four regions studied (Kansas, Massachusetts, Oregon, and Arizona) was a hybrid incorporating wind technology. The cost differences between these regions, however, were dependent upon region. Future studies will be necessary as it is difficult to estimate meteorological trends for other regions.

Category: Engineering

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Introduction

According to Richard Perez, editor of *Home Power* magazine, approximately 180,000 U.S. homes are not connected to a public power source or utility grid (Richard Perez, email to author, August 2, 2000). These homes are either without an electric power supply or provide their own power through the use of fossil-fueled generators, photovoltaics, or wind turbines. Batteries and inverters are additional components that are likely to be used with these power sources. Any power system that incorporates two or more of the following is referred to as a *hybrid* power system: photovoltaic (PV) panels, wind turbines, or diesel/propane/gasoline generators (Figure 1). Hybrid power allows stand alone power systems to operate at maximum effectiveness as one power component is supported by the other power components of the system.

Remote homeowners are often left with many decisions and little knowledge regarding the most cost-effective system for providing power to their homes. Most remote homeowners use fossil-fueled generators or a *hybrid* of photovoltaic (solar) panels with a generator (Figure 2). According to a survey of subscribers new to *Home Power*, 80.6% use PV systems and half of this 80.6% also incorporate a generator. Only 19.4% of this population use wind technology to power their homes (Richard Perez, email to author, August 2, 2000) (Figure3,4). Consumers have limited access to information regarding the best configuration of power components for their regional meteorological conditions along with optimal cost scenarios.

The goal of this study is to determine the optimal configuration of residential power sources relevant to different regions in the United States, including systems with any or all of the previously discussed components of a potential hybrid system. The hypothesis formulated is: remote homeowners who currently own power systems without a wind turbine are *not* operating the most cost-effective systems, regardless of their geographical region. This hypothesis was tested using the computer simulation model HOMER, the Hybrid Optimization Model for Electric Renewables. Although HOMER was initially developed to provide optimization models for developing countries, it is also an appropriate reference tool for this study of remote homes in the United States.

Methods and Materials

The primary method used in this research was the exercise of the HOMER optimization model. The National Renewable Energy Laboratory, under the guidance of Peter Lilienthal and Tom Lambert, developed HOMER, a computer model for optimizing electrical resources. HOMER "simulates and optimizes hybrid power systems, which are standalone power plants that employ some combination of wind turbines, photovoltaic panels, or diesel generators to produce electricity" (Lambert 2000). HOMER is capable of simulating over 1000 different hybrid systems in a minute. HOMER has two types of data windows: Inputs and Outputs. The Inputs provide the definition of the search space and the Outputs provide the results. The Inputs consist of the following: loads, resources, components, and optimizations.

Specific simulations were prepared, which define the span of the search space, and certain sensitivities, each resulting in an optimum being chosen from the search space. A simulation with the household energy usage of 7.52 kWh/d was selected. This load size was determined using seasonal approximations for remote homes. Local data regarding solar radiation monthly averages (in kWh/m^2/day) and hourly wind speed (in meters/second) were input. The regions chosen for this study were Kansas, Massachusetts, Oregon, and Arizona. The solar data was from Dodge City, KS, Worcester, MA, Pendleton, OR, and Prescott, AZ. The wind data was from Russell, KS, Holyoke, MA, Pendleton, OR, and Kingman, AZ. Although the solar and wind data are from different locations, they have comparable latitudes and climates (except Arizona). The components of a power system allowed were: PV panels, wind turbines, generator, battery, and inverter. For each of these components, information regarding typical market prices and power generation statistics are input. These were the primary inputs, which provide the base data for the optimization process.

Several input parameters are allowed to vary within a range. Each unique combination of all the inputs is a simulation. The data ranges provide the scope of the search space and need to encompass all feasible conclusions. The ranges chosen were under the categories of PV Array, Turbine 2 (Turbine 1 was not used), Diesel (generator), Battery, and Inverter. For example, PV array ranges were from zero kW to 4kW, as indicated by the load size and necessary search space. This range was then divided into eight sub-divisions, in order to determine the optimal size of the PV array. HOMER will not search for a system that is not defined in this space. Therefore, if the optimal system consists of 2kW of PV, but HOMER is only given 1kW and 3kW under the optimizations window, then the optimal system will be passed over in lieu of the next best choice that has a defined PV component. Wind turbines were categorized in HOMER by the number of turbines (from 0 to 2) necessary to optimize the power output. The Diesel (generator) variable range consisted of a variety of generator sizes (in kW), along with the Inverter variable ranges (in kW). Batteries were varied using typical "market" size ranges (in kWh).

These simulations used 0.5$/liter for a fixed fuel price and negligible (0.3%) unserved energy. The "unserved energy" percentage refers to the percentage of the year during which no energy is being provided to the property. The negligible unserved energy chosen allowed for up to 2 hours a month as the maximum unserved energy for the home.

Once the initial characteristics of each HOMER run were standardized, meaning once it was determined which variables were important and which were not, the solar radiation and wind data for the four different regions of the United States were input in order to determine if there were any regional variations in optimal power system. A new HOMER run was executed for each region. HOMER then ranked each of the simulations according to “Net Present Cost” (NPC), which is the total cost over the lifetime of the system using current monetary values. The established lifetime of each system was 20 years. HOMER also provided data regarding the initial capital cost and the annualized cost. The objective of this research was to determine optimal (least-cost) power system for each region and compare these results to the lowest-cost system that did not include a wind turbine.

Results

Kansas

Based on the data provided by NREL for Dodge City and Russell, KS, in 1977, the annual average global solar insolation was 4.9 kWh/m^2/day and the annual average wind speed was 5.7 m/s, respectively. According to HOMER, using the control variables specified, the “optimal” system, meaning the least-cost, for this load size and location is a hybrid wind turbine, diesel generator, battery, and inverter system (Figure 5). HOMER recommends that 2 wind turbines of rated power 1.0 kW, a 1.0 kW generator, an 18.0 kWh battery bank capacity (meaning approximately 2 days of energy storage), and a 2.0 kW inverter capacity be purchased as the optimal system, for a capital cost of $10580. Over the lifetime of the system, the net present cost (NPC), which is a sum of the capital cost and the total cost to maintain this system with these components, would be $20940. Typically, 89% of the total energy production will be the result of renewable resources and the generator will be running approximately 729 hours per year. The annual fuel usage is 386 liters.

The first system that does not involve a wind turbine incorporates 1.0 kW of PV along with a 1.0 kW generator, 18.0 kWh in battery bank capacity, and an inverter capacity of 2.0 kW for an initial cost of $10580. The NPC over the lifetime of the system is $28349, which is 35% more expensive than the optimal system. This system generates 48% of its energy from renewable resources, and uses 2015 annual hours of generator energy. This increase in generator run time causes this system to use 688 more liters of diesel (1074 liters) than the optimal wind/generator hybrid power system. These results are summarized in Table 1.

Massachusetts

The data provided for Worcester and Holyoke, MA, in 1979 had an annual global solar radiation average of 3.8 kWh/m^2/day and a 3.3 m/s annual average wind speed. According to HOMER, the ideal system in this region of Massachusetts is a hybrid including PV, a wind turbine, generator, battery, and inverter (Figure 6). The components necessary to fulfill this primary load of 2744 kWh/yr. are .8 kW of PV, one wind turbine of rated power 1.0 kW, a 1.0 kW capacity generator, a battery bank capacity of 18.0 kWh, and a 2.0 kW inverter. The capital cost of this configuration is $12080. The lowest NPC is $29090. This system captures 49.6% of its energy production from renewable sources. The generator will typically be running 1930 hours per year and use 1018 liters of fuel.

The least-cost system absent a wind turbine consists of 1.0 kW of PV, 1.0 kW in generator capacity, 18.0 kWh in battery bank capacity, and 2.0 kW in inverter capacity, for an initial capital cost of $10580. This capital cost is less than the capital cost for the optimal system. However, the NPC of this system is $29901, which is 3% more expensive than the optimal. Of the total production, 39% is from renewable resources. This system runs the generator 2347 hours a year, 417 more than the wind system, and uses 1236 liters of fuel, 218 liters more than the optimum.

Oregon

Oregon is the only region for which the data for solar and wind resources are from the same city. The data was taken from Pendleton, OR, in 1992. The average global solar radiation index was 5.4 kWh/m^2/day, and the average annual wind speed was 3.5 m/s. The optimization generated was as follows: .8 kW PV, one wind turbines of rated power 1.0 kW, 1.0 kW capacity generator, 18.0 kWh capacity battery bank, and 2.0 kW capacity inverter (Figure 7). The capital cost for this system is $12080 and the NPC is $26525. This system will produce 67% of its energy from renewable resources. The generator will run 1393 hours per year, using 731 liters of fuel annually.

The least-cost system without a wind turbine is composed of 1.0 kW of PV, 1.0 kW capacity generator, and 18.0 kWh battery bank with a 2.0 kW inverter capacity. The initial capital cost is $10580 and the NPC is $27526. The capital cost for this system is less than that for the optimal but the NPC is 4% more expensive. This configuration will produce 55% of its energy from renewable energy sources. The generator will typically run 1827 hours annually, using 963 liters of fuel per year. A hybrid that does not use wind technology uses 232 more liters of non-renewable fossil fuel than the optimal.

Arizona

The data available for Arizona was from Prescott (solar) and Kingman (wind), in 1985. The annual average global solar radiation was 4.2 kWh/m^2/day, and the annual average wind speed was 4.5 m/s. HOMER calculated the optimal system as a hybrid configuration including PV, a wind turbine, generator, and an inverter (Figure 8). The optimal components are .5 kW of PV, one wind turbine of rated power 1.0 kW, a generator with a 1.0 kW power output, a battery bank with a capacity of 18.0 kWh and an inverter with a 2.0 kW capacity. The initial capital cost of this hybrid is $10580 and the NPC is $27157. Typically, 54% of the energy produced will be from renewable resources. The generator will typically run 1871 hours annually, using 980 liters of fuel.

The least-cost system without a wind component has 1.0 kW of PV, 1.0 kW of diesel generator capacity, 18.0 kWh of battery capacity, and 2.0 kW of inverter capacity, for a total capital cost of $10580. The net present cost comes to $30176. It will produce 38% of its energy from renewable sources. The generator will run 2420 hours annually and use 1270 liters of fuel, exceeding the optimal system by 290 liters.

Discussion

Kansas

Of the four regions studies, Kansas has the most favorable meteorological conditions for renewable energy usage. Homeowners in Kansas not using wind technology, but using

PV/generator systems, are spending on average $8000 more over the 20 year lifetime of their system than they would had they instead added a wind turbine to their initial system. Their savings had they invested in a turbine would have been about 36%. These homeowners are also running their diesel generators 2.8 times longer then they would using wind energy and using 2.8 times more diesel fuel. Both economically and ecologically, the use of a wind turbine hybrid system is the more appropriate system than the PV-generator configuration.

Massachusetts

The Massachusetts analysis provides the least dramatic conclusions of the four regions. However, the optimal system in Massachusetts is still a hybrid incorporating wind technology. The PV without wind system uses 20% more diesel fuel than the optimal system and runs this generator 20% more frequently. Conservation of fossil fuels and reduction of emissions are benefits of incorporating a wind turbine. Regardless of system, Massachusetts seldom had an option with a renewable percentage greater than 50%. The capital cost of a system with a wind turbine is 12% more than the cost without a turbine and, after the 20-year lifetime, the consumer has only saved about 3% over a PV only system. Using wind technology would be only slightly less expensive.

Oregon

Oregon's optimal electrical system is comparable to that of Massachusetts. The optimal is a hybrid incorporating wind technology, but the system without wind is only about $1000 more in NPC. The capital cost of the windless system is less expensive than the hybrid incorporating wind. The PV/generator system uses the generator 30% longer than the system with a wind turbine and uses 30% more fossil fuel. Oregon also tends to rank low on the percentage of renewables used: the optimal is 67% while the PV only is 55%. Using wind technology does reduce the net present cost of the system, but by a marginal degree.

Arizona

Next to Kansas, Arizona has the largest savings when using wind technology. The optimal system is, again, a hybrid using wind technology. By investing in a wind turbine over a PV only system, Arizona homeowners may save more than 10% over the 20-year lifetime of the system. The capital costs are identical regardless of the addition of wind or not. Without a turbine, Arizona homeowners will typically run their generators 30% longer while increasing their fuel usage by the same amount. The argument for a wind turbine in Arizona is not only the savings in fuel usage but also the $3000 saved over the lifetime of the system.

Conclusions

In these four regions, it has been reasonably shown that a hybrid electrical system incorporating wind technology is generally the optimum in terms of net present cost. This is consistent with the hypothesis of the study. However, the range between the first solution and the first PV-only solution is variable and dependent upon regional and meteorological conditions. Kansas has the strongest argument in favor of wind and even ranks a system without PV as the optimum. Arizona has the second strongest argument, although with a very low renewable fraction. Both Oregon and Massachusetts, although having optimal systems incorporating wind, have weaker arguments for wind, taking into account the minimal cost differences between the optimal wind solution and the PV-only solution. In any case, two conclusions may be made from this preliminary research: wind hybrid systems have similar or lower costs than PV-only systems and regional differences do affect electrical production and system feasibility. Further studies are being proposed using HOMER, as, especially in Arizona, the meteorological data is questionable.

Acknowledgements

I would like to express my deepest thanks to Jim Green for orchestrating and patiently providing the advice and input needed to fulfill this research. I would like to thank Tony Jimenez, Peter Lilienthal, and Tom Lambert for providing the instruction and data concerning the HOMER program. I would like to thank Leigh Ann Kudloff for her encouragement and advice. I wish to thank Robi Robichaud and John Sepich for their continued support and organization of my internship. Finally, I would like to thank the Department of Energy for the organization, creation, and funding of this program. I would also like to thank all of those involved with the Department of Energy, National Renewable Energy Laboratory, and National Wind Technology Center for their hard work and expertise in my research experiences.

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Tables

KANSAS SOLUTIONS				**MASSACHUSETTS SOLUTIONS**			
Large 7.519 kWh/d	Optimal	First PV-only System	Difference (Optimal/PV only)	Large 7.519 kWh/d	Optimal	First PV-only System	Difference (Optimal/PV only)
PV (kW)	0.0	1.0		PV (kW)	0.8	1.0	
BWC XL.1 (#)	2.0	0.0		BWC XL.1 (#)	1.0	0.0	
Diesel (kW)	1.0	1.0		Diesel (kW)	1.0	1.0	
Battery (kWh)	18.0	18.0		Battery (kWh)	18.0	18.0	
Inverter (kW)	2.0	2.0		Inverter (kW)	2.0	2.0	
Renewable %	89.0%	47.7%		Renewable %	49.6%	39.4%	
Generator Run Time (hrs/yr)	729.0	2015.0	176.5%	Generator Run Time (hrs/yr)	1930.0	2347.0	21.6%
Diesel Fuel Usage (liters/yr)	386.0	1074.0	177.8%	Diesel Fuel Usage (liters/yr)	1018.0	1236.0	21.4%
Capital Cost	$10,580	$10,580	0.0%	Capital Cost	$12,080	$10,580	-12.4%
Total NPC (US$)	$20,940	$28,349	35.4%	Total NPC (US$)	$29,090	$29,901	2.8%

OREGON SOLUTIONS				**ARIZONA SOLUTIONS**			
Large 7.519 kWh/d	Optimal	First PV-only System	Difference (Optimal/PV only)	Large 7.519 kWh/d	Optimal	First PV-only System	Difference (Optimal/PV only)
PV (kW)	0.8	1.0		PV (kW)	0.5	1.0	
BWC XL.1 (#)	1.0	0.0		BWC XL.1 (#)	1.0	0.0	
Diesel (kW)	1.0	1.0		Diesel (kW)	1.0	1.0	
Battery (kWh)	18.0	18.0		Battery (kWh)	18.0	18.0	
Inverter (kW)	2.0	2.0		Inverter (kW)	2.0	2.0	
Renewable %	66.7%	55.0%		Renewable %	53.6%	37.5%	
Generator Run Time (hrs/yr)	1393.0	1827.0	31.2%	Generator Run Time (hrs/yr)	1871.0	2420.0	29.3%
Diesel Fuel Usage (liters/yr)	731.0	963.0	31.7%	Diesel Fuel Usage (liters/yr)	980.0	1270.0	29.6%
Capital Cost	$12,080	$10,580	-12.4%	Capital Cost	$10,580	$10,580	0.0%
Total NPC (US$)	$26,525	$27,526	3.8%	Total NPC (US$)	$27,157	$30,176	11.1%

Table 1

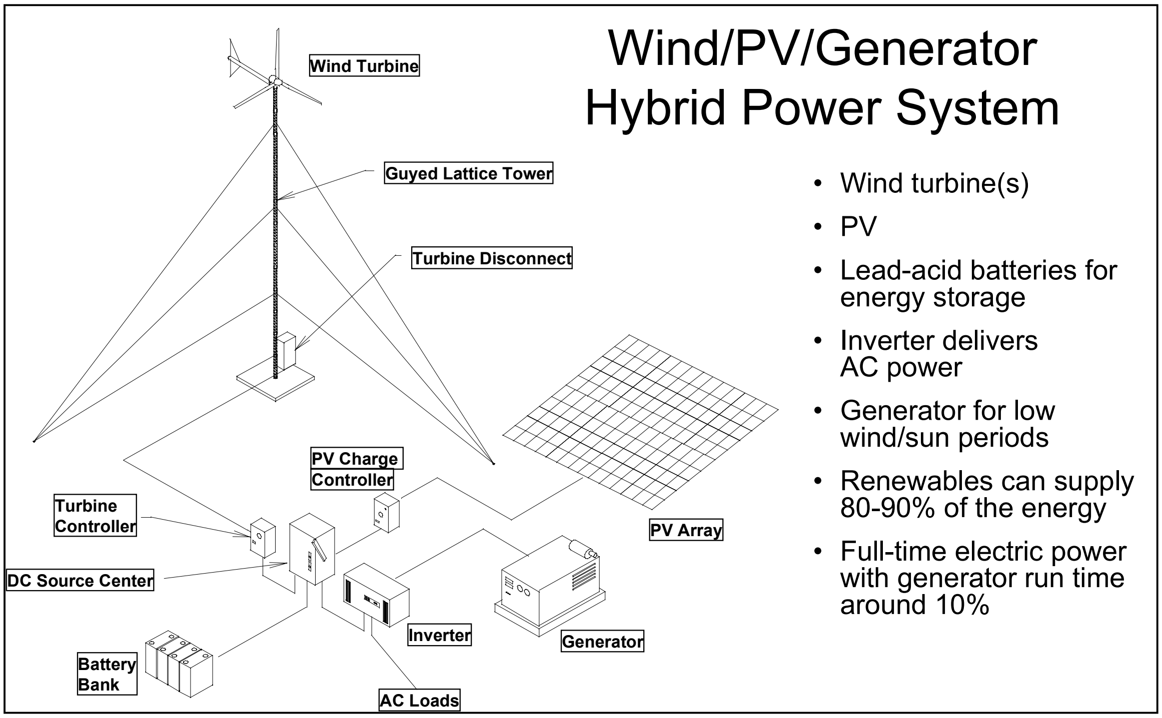


Figure 1: Diagram of Wind/PV/Generator Hybrid Power System

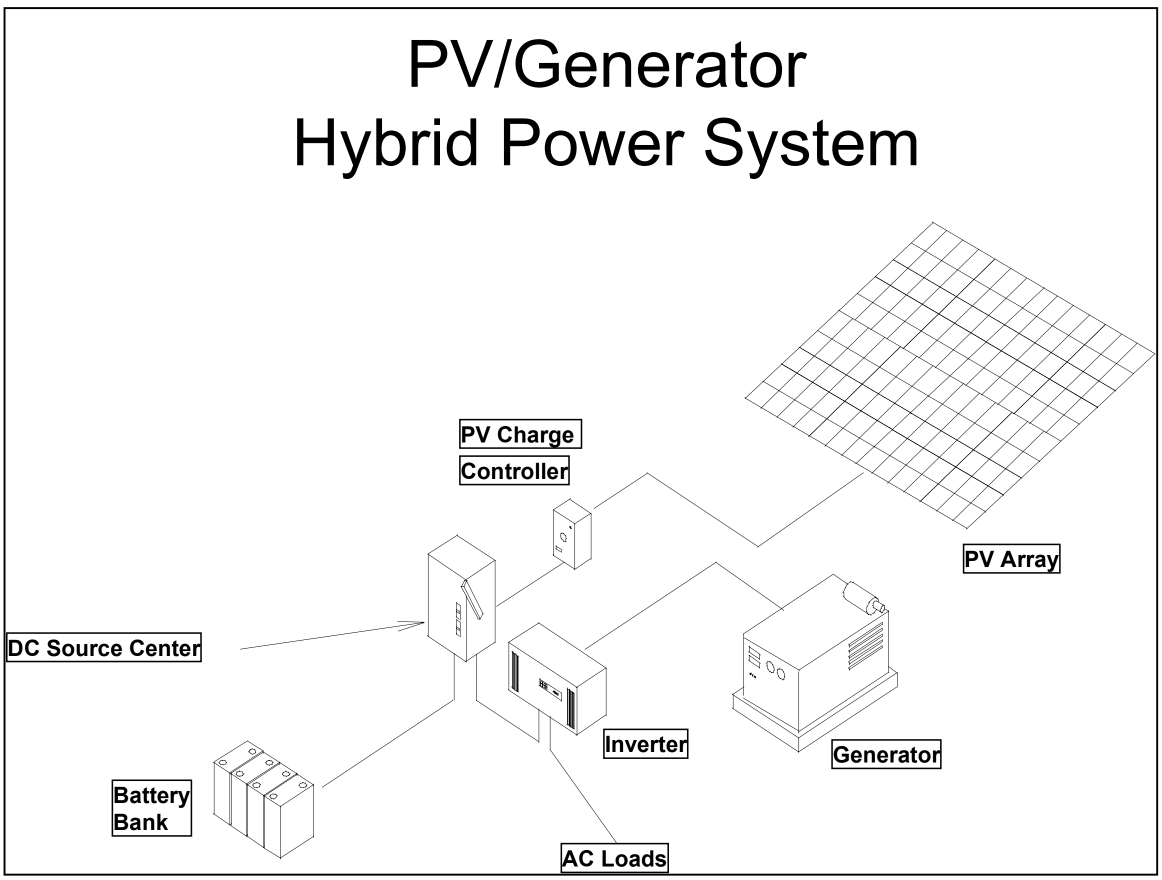


Figure 2: Diagram of PV/Wind Generator Hybrid Power System

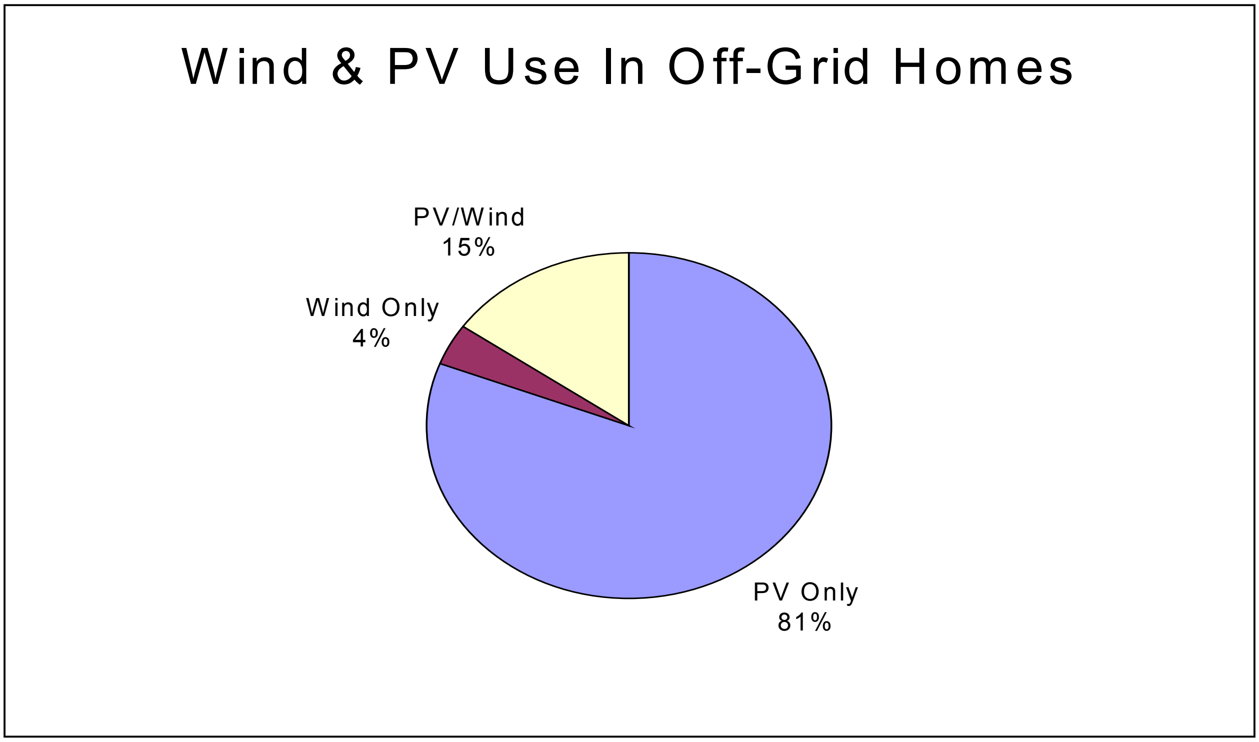


Figure 3: Graphical representation from survey of Homer Power subscribers

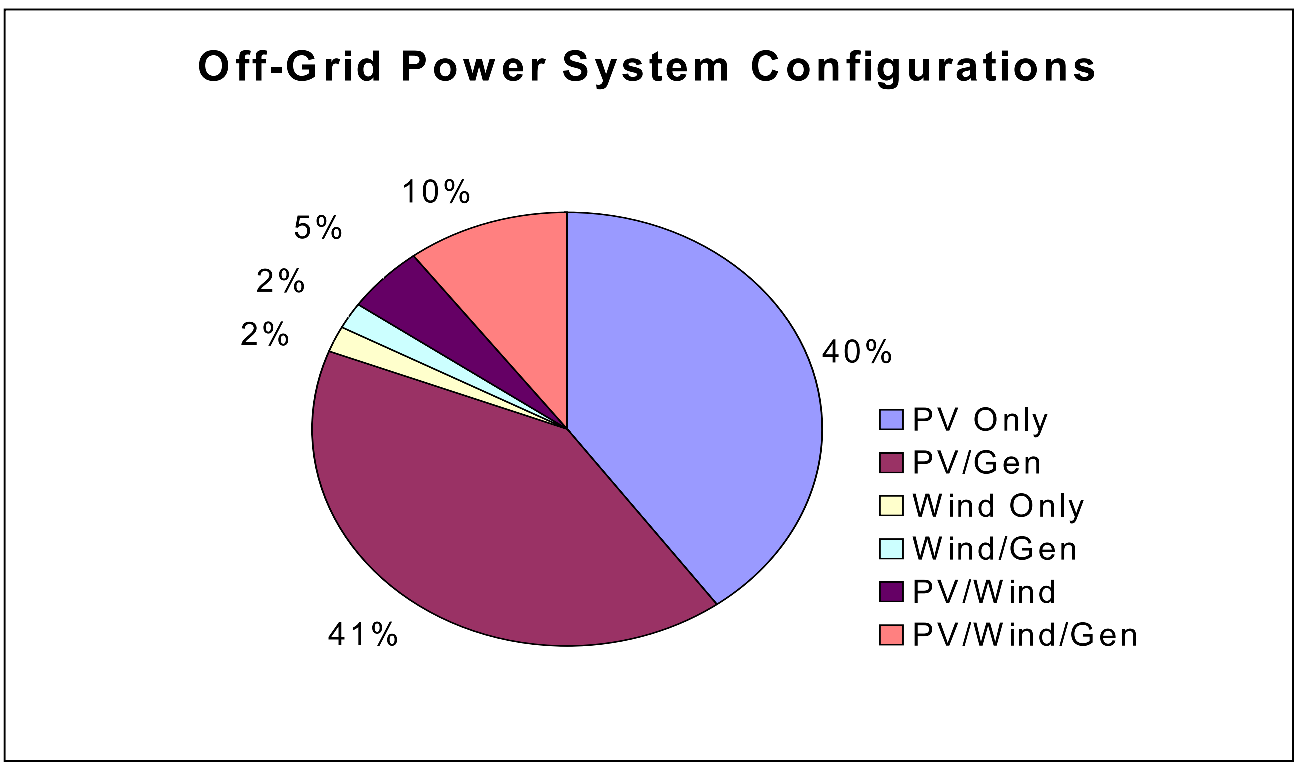


Figure 4: Graphical representation from survey of Home Power subscribers

Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.00	0	2	1	18	2	CM	$ 10,580	$ 20,940	0.624	0.89	0.00	0.44	3.0	386	729
0.20	0	1	1	18	2	CM	$ 8,780	$ 21,145	0.630	0.74	0.00	0.16	2.8	610	1146
0.75	0	3	0	40	2	CM	$ 18,900	$ 28,166	0.841	1.00	0.00	0.64	5.0	0	0
1.00	0	0	1	18	2	CM	$ 10,580	$ 28,349	0.844	0.48	0.00	0.03	2.3	1,074	2015
0.00	0	2	1	0	2	CM	$ 9,500	$ 28,463	0.848	0.83	0.00	0.52	5.0	1,349	4038
0.20	0	2	1	0	2	CM	$ 10,700	$ 28,528	0.850	0.85	0.00	0.54	5.0	1,251	3773
0.00	0	4	0	60	2	CM	$ 18,600	$ 31,452	0.939	1.00	0.00	0.68	5.0	0	0
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,192	0.959	0.00	0.00	0.00	2.1	2,029	3832
1.00	0	0	1	0	2	CM	$ 9,500	$ 38,647	1.151	0.47	0.00	0.17	5.0	2,234	6602
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
3.00	0	0	0	80	2	CM	$ 25,800	$ 40,381	1.205	1.00	0.00	0.29	5.0	0	0

Figure 1: Homer results for Kansas

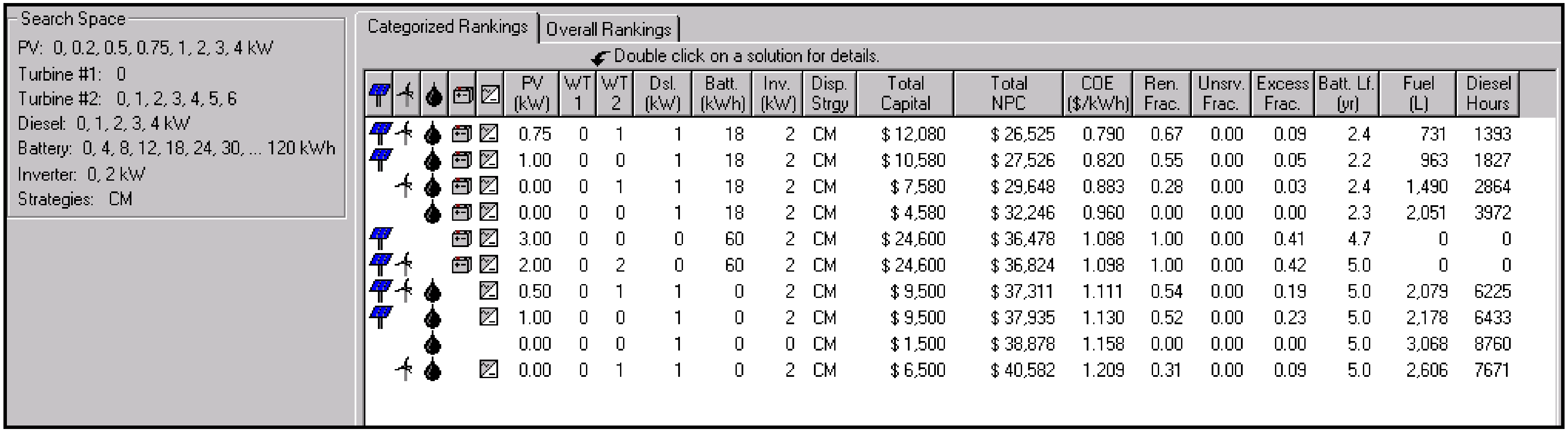
Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.75	0	1	1	18	2	CM	$ 12,080	$ 29,090	0.866	0.50	0.00	0.02	2.6	1,018	1930
1.00	0	0	1	18	2	CM	$ 10,580	$ 29,901	0.890	0.39	0.00	0.01	2.3	1,236	2347
0.00	0	1	1	18	2	CM	$ 7,580	$ 30,793	0.917	0.20	0.00	0.00	2.5	1,617	3112
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
1.00	0	1	1	0	2	CM	$ 12,500	$ 39,618	1.180	0.56	0.00	0.19	5.0	2,012	6044
0.20	0	0	1	0	0	CM	$ 2,700	$ 40,124	1.195	0.09	0.00	0.09	5.0	3,068	8760
0.00	0	2	1	0	2	CM	$ 9,500	$ 41,318	1.231	0.40	0.00	0.15	5.0	2,387	7004
3.00	0	3	0	60	2	CM	$ 33,600	$ 46,596	1.391	1.00	0.00	0.45	5.0	0	0

Figure 2: Homer results for Massachusetts



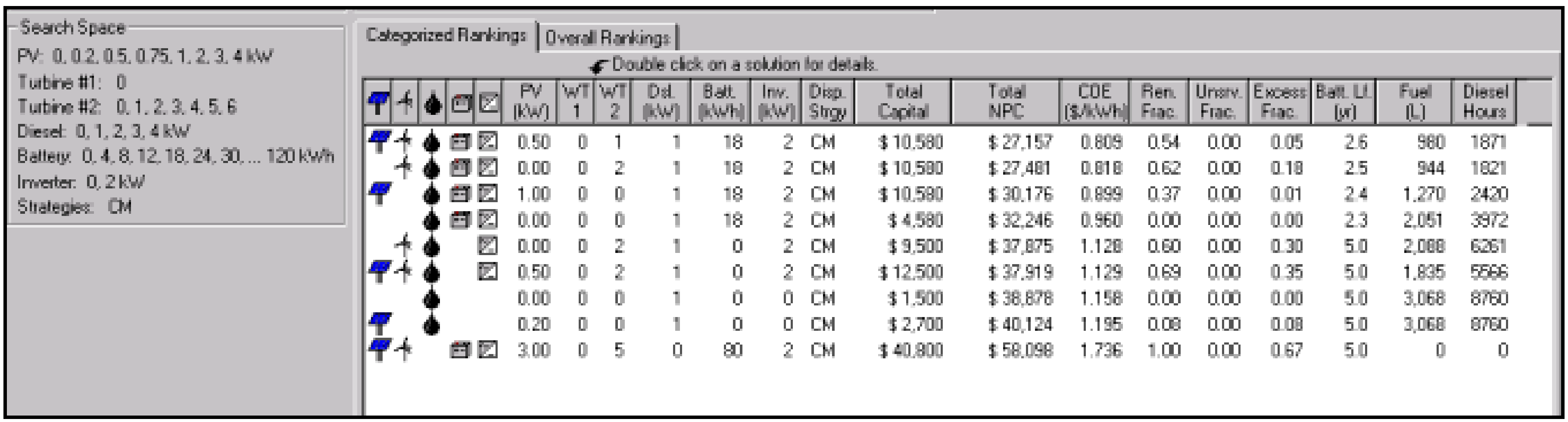
Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.75	0	1	1	18	2	CM	$ 12,080	$ 26,525	0.790	0.67	0.00	0.09	2.4	731	1393
1.00	0	0	1	18	2	CM	$ 10,580	$ 27,526	0.820	0.55	0.00	0.05	2.2	963	1827
0.00	0	1	1	18	2	CM	$ 7,580	$ 29,648	0.883	0.28	0.00	0.03	2.4	1,490	2864
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
3.00	0	0	0	60	2	CM	$ 24,600	$ 36,478	1.088	1.00	0.00	0.41	4.7	0	0
2.00	0	2	0	60	2	CM	$ 24,600	$ 36,824	1.098	1.00	0.00	0.42	5.0	0	0
0.50	0	1	1	0	2	CM	$ 9,500	$ 37,311	1.111	0.54	0.00	0.19	5.0	2,079	6225
1.00	0	0	1	0	2	CM	$ 9,500	$ 37,935	1.130	0.52	0.00	0.23	5.0	2,178	6433
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
0.00	0	1	1	0	2	CM	$ 6,500	$ 40,582	1.209	0.31	0.00	0.09	5.0	2,606	7671

Figure 3: Homer results for Oregon



Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.50	0	1	1	18	2	CM	$ 10,580	$ 27,157	0.809	0.54	0.00	0.05	2.6	980	1871
0.00	0	2	1	18	2	CM	$ 10,580	$ 27,481	0.818	0.62	0.00	0.18	2.5	944	1821
1.00	0	0	1	18	2	CM	$ 10,580	$ 30,176	0.899	0.37	0.00	0.01	2.4	1,270	2420
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
0.00	0	2	1	0	2	CM	$ 9,500	$ 37,875	1.128	0.60	0.00	0.30	5.0	2,088	6261
0.50	0	2	1	0	2	CM	$ 12,500	$ 37,919	1.129	0.69	0.00	0.35	5.0	1,835	5566
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
0.20	0	0	1	0	0	CM	$ 2,700	$ 40,124	1.195	0.08	0.00	0.08	5.0	3,068	8760
3.00	0	5	0	80	2	CM	$ 40,800	$ 58,098	1.736	1.00	0.00	0.67	5.0	0	0

Figure 4: Homer results for Arizona